Memory, inheritance and ecolution: The Jo Nagai experiment and the reconfiguration of evolutionary mechanisms

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"*Evolution is not a merit contest, but a travel journal written by the survivors, where the pencil is wielded by the environment, the ink is provided by epigenetics, and the wind that sometimes erases the pages is called chance.*"

ABSTRACT

The experiment conducted by Jo Nagai, a 10-year-old Japanese student, has provided empirical evidence that butterflies (*Papilio xuthus*) can retain memories acquired during their larval stage through metamorphosis, and that this learned aversion is transmitted to their offspring and grandchildren without direct exposure to the original stimulus. These findings, still undergoing peer review, constitute robust evidence of transgenerational epigenetic inheritance in Lepidoptera and offer a unique opportunity to revisit the foundations of evolutionary theory. This article argues that the phenomenon observed by Nagai not only confirms the survival of memory through metamorphosis—challenging the notion that the complete reorganization of the nervous system during pupation eliminates all prior experience—but also, by demonstrating its transmission to unexposed generations, points to a mechanism of inheritance of acquired characteristics that epigenetics has begun to unveil. The implications of these results for the understanding of evolution are discussed, proposing that epigenetic inheritance constitutes a rapid adaptation mechanism to the environment that operates in parallel with natural selection and genetic drift, and that chance and environmental context play as determining a role as organic "fitness" in the survival and evolution of species.

Keywords: transgenerational epigenetic inheritance, metamorphosis, memory, evolution, natural selection, genetic drift, Lamarckism, Jo Nagai.

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1. INTRODUCTION

The theory of evolution by natural selection, formulated by Charles Darwin in the 19th century, has been the cornerstone of biology for over 150 years. According to this model, genetic variation arises randomly (through mutations and recombination), and the environment acts as a filter favoring the reproduction of those organisms whose variants confer an advantage in a given context. However, this paradigm has been challenged since its inception by Jean-Baptiste Lamarck's theory of the inheritance of acquired characters, which posited that experiences and the use or disuse of organs during an individual's lifetime could be inherited.

During the 20th century, the modern synthesis of evolution integrated Mendelian genetics with natural selection, relegating Lamarckism to the realm of pseudoscience. However, the discovery of **epigenetics**—chemical modifications of DNA and histones that regulate gene expression without altering the nucleotide sequence—has revived the possibility that environmental experiences may leave a heritable mark. Transgenerational epigenetic inheritance (TEI) has been documented in plants, nematodes, and fruit flies, and has been proposed as a mechanism for rapid adaptation to changing environments.

Holometabolous insects, which undergo complete metamorphosis—a radical reorganization of their body plan and nervous system—have been the subject of study in this context. In 2008, Martha Weiss and collaborators demonstrated that *Manduca sexta* moths could retain memories from their larval stage after metamorphosis. The experiment by Jo Nagai, initiated when he was in second grade, took this observation a step further: not only did he confirm memory retention in *Papilio xuthus* butterflies, but he also found evidence that the learned aversion was transmitted to offspring and grandchildren.

This article analyzes Nagai's findings in light of contemporary evolutionary biology and argues that transgenerational epigenetic inheritance, together with phenotypic plasticity and the role of chance (genetic drift and catastrophic events), demands a revision of the dominant narrative about evolution. It is proposed that evolution is not a teleological process that "selects" the "fittest," but a record of survivors shaped by the continuous interaction between environment, genetic and epigenetic inheritance, and historical contingency.

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2. MATERIALS AND METHODS

2.1. Subject of Study

Jo Nagai, a student at Ibuki East Elementary School in Kobe, Japan, began rearing *Papilio xuthus* (Asian swallowtail) butterflies at home. After observing that butterflies he had raised from the larval stage returned to his hand after being released, Nagai hypothesized that they might retain memories from their earlier stage.

2.2. Experimental Design

Nagai contacted entomologist Martha Weiss of Georgetown University, who had published a 2008 study on memory retention in moths. Following several years of correspondence, Nagai adapted the experimental protocol to his home environment.

Approximately 100 larvae were incubated. One group of caterpillars underwent aversive conditioning: they were exposed to the scent of lavender essential oil while a mild but unpleasant vibration was applied using a portable muscle stimulation device. The training was repeated three times daily. A control group received no training.

2.3. Memory Retention Test

Following eclosion, the adult butterflies were tested in a Y-shaped maze. One arm of the maze contained the scent of lavender; the other did not. Each butterfly's choice was recorded.

2.4. Transgenerational Inheritance Test

Nagai reared the offspring (children and grandchildren) of the trained butterflies. These generations were never exposed to the lavender scent or the vibratory stimulus. They were subjected to the same Y-maze test to evaluate their aversion to the scent.

2.5. Sample Size and Analysis

Nagai compiled his findings in a 33-page document and presented them at the International Congress of Entomology (ICE2024) in Kobe and at the 73rd Annual Meeting of the Ecological Society of Japan in Kyoto (March 2026) with a poster titled "*Epigenetic Transmission of Learned Larval Memory across Generations in Papilio xuthus*".

3. RESULTS

3.1. Memory Retention Through Metamorphosis

Control group butterflies showed random choice between the two maze arms (approximately 50%). In contrast, **80%** of the butterflies that had been trained as caterpillars avoided the arm with lavender scent. This result indicates that the association between the scent and the unpleasant stimulus was maintained despite the complete reorganization of the nervous system during metamorphosis.

3.2. Transgenerational Inheritance of Aversion

The offspring of trained butterflies, which had never been exposed to lavender or vibration, also showed significant aversion to the scent. The data show a decreasing trend across generations: trained parents avoided lavender in **70.9%** of cases; the filial generation (children) in **64.8%**; and the grandchild generation in **60.0%**. The wild control group showed avoidance of **51.0%**.

3.3. Implications

These results suggest that the aversive experience of the parents induced a heritable change that predisposed offspring to avoid the scent, consistent with a transgenerational epigenetic inheritance mechanism. Nagai and Weiss are currently preparing the formal publication of these results.

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4. DISCUSSION

4.1. Memory Through Metamorphosis: A Challenge to Classical Neurobiology

The finding that 80% of butterflies retained lavender aversion after metamorphosis challenges the assumption that the complete reorganization of the nervous system during pupation entails the loss of all prior memory. This

result, which replicates and extends Weiss's 2008 study, suggests that memory may be encoded not only in synaptic connections but also in epigenetic mechanisms or in the structure of neural circuits that persist through metamorphosis.

4.2. Transgenerational Epigenetic Inheritance: A Rediscovered Lamarckian Mechanism

The transmission of aversion to unexposed offspring constitutes the strongest evidence to date of transgenerational epigenetic inheritance in Lepidoptera. This phenomenon, documented in other insects, provides a mechanism by which environmental experiences of one generation can influence the phenotype of subsequent ones.

In essence, Nagai's experiment demonstrates that **learning is not merely a transient neuronal phenomenon, but can leave a chemical (epigenetic) imprint that transcends the individual's death and is imprinted on its descendants**. This is the central intuition of Lamarckism, now rescued by epigenetics.

However, it is crucial to note that epigenetic inheritance does not equate to Lamarckian genetic inheritance in the strict sense. Epigenetic marks (DNA methylation, histone modifications, non-coding RNAs) do not alter the DNA sequence but regulate its expression. Moreover, these marks are usually reversible and tend to disappear after a few generations if the environmental stimulus ceases. In Nagai's experiment, aversion decreased from 70.9% in parents to 60.0% in grandchildren, suggesting a gradual "erasure" of the epigenetic mark. Epigenetic inheritance is therefore a mechanism of **rapid and reversible adaptation** to the environment, a "bet" that nature makes on the environment that offspring will inherit.

4.3. The Environment as Trigger and Programmer

Nagai's results clearly illustrate the role of the environment as a **trigger** of adaptive responses. The external stimulus (lavender scent associated with vibration) did not create a new mutation; it activated a signaling pathway that, through epigenetic mechanisms, altered gene expression and generated an aversive behavior. This response was not random but **directed** by the stimulus: the environment "programmed" the gene to produce a protein or modification that resulted in avoidance behavior.

This finding has profound implications for evolutionary theory. Phenotypic plasticity—the ability of a genotype to produce different phenotypes in response to the environment—is an adaptation mechanism that does not require waiting for a random mutation to provide the solution. When an environmental stimulus acts on an entire population, it can induce an adaptive response in all individuals simultaneously, accelerating the evolutionary process without the need for the "less fit" to die.

4.4. Natural Selection, Genetic Drift, and the Role of Chance

The teleological language used in evolutionary biology—"nature selects," "the fittest survive"—has been subject to philosophical criticism. **Nature does not "select" anything; it has no mind, no finger, no preferences**. "Natural selection" is simply the name we give to **survival bias**: those organisms that, through a combination of inheritance, plasticity, and above all, **luck**, manage to survive the vicissitudes of the environment are the only ones that leave descendants.

Genetic drift—random changes in allele frequencies due to chance—is a fundamental evolutionary mechanism that operates independently of adaptation. Catastrophic events (asteroids, eruptions, abrupt climate changes) can eliminate entire populations regardless of any adaptive "advantage". The history of life on Earth is dominated by contingency: dinosaurs did not go extinct due to poor adaptation, but because of an asteroid.

Therefore, evolution is not a process that requires "the best organic adaptations transmitted intergenerationally." What it requires is **adaptations that are good enough for the present context, and that have the luck not to be erased by a cataclysm**. The giraffe with the longer neck is not "better" than the one with the shorter neck; it is *different*. If the climate changes and the high leaves disappear, the short-necked one (which was "worse" yesterday) is today the "best" by pure environmental coincidence.

4.5. Toward an Expanded Evolutionary Synthesis

Nagai's findings, together with advances in epigenetics, demand a revision of the dominant evolutionary narrative. We propose that evolution is the result of the interaction of multiple mechanisms:

1. **Genetic inheritance (mutations and recombination):** provides long-term variation, but is slow and random.
2. **Epigenetic inheritance:** allows rapid and reversible adaptation to the environment, transmitting "memories" of past experiences.

3. **Phenotypic plasticity:** allows organisms to adjust their phenotype in response to the environment without genetic changes.
4. **Genetic drift and catastrophic events:** introduce an element of chance that can override any adaptive advantage.

This integrative vision, which some authors have called the "unified theory of evolution," recognizes that **the environment not only filters but also writes** (through epigenetics), and that **chance is as important an actor as necessity**.

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5. CONCLUSIONS

The experiment by Jo Nagai, a 10-year-old child, has provided empirical evidence that:

1. *Papilio xuthus* butterflies can retain memories acquired during their larval stage through metamorphosis.
2. This learned aversion is transmitted to offspring and grandchildren without direct exposure, pointing to a mechanism of transgenerational epigenetic inheritance.
3. The environment acts as a trigger for adaptive responses that can be inherited, confirming the central intuition of Lamarckism, although with a mechanism (epigenetic) different from that originally proposed.
4. Evolution is not a teleological process of "selection of the fittest," but a record of survivors shaped by the interaction between inheritance (genetic and epigenetic), plasticity, and a fundamental component of chance (genetic drift and catastrophic events).

These findings have profound implications for evolutionary biology, neurobiology, and the philosophy of science. Jo Nagai's story demonstrates that curiosity and careful observation, even in a home environment, can lead to discoveries that challenge established paradigms.

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